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COMPUTER SIMULATION OF ANOMALIES CREATED BY AN ARRAY OF FERROUS--ETC(U)
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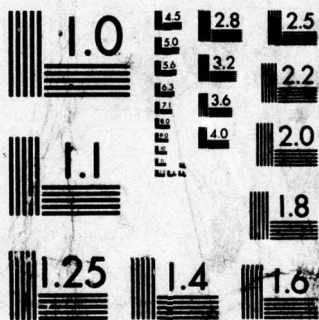
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COMPUTER SIMULATION OF ANOMALIES CREATED BY AN ARRAY OF
FERROUS OBJECTS IN THE EARTH'S MAGNETIC FIELD (U)

by

R.W. Henrich

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COMPUTER SIMULATION OF ANOMALIES CREATED BY AN ARRAY OF
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ABSTRACT

→ This report describes a FORTRAN IV computer simulation of a three-dimensional array of ferrous objects and its effect on the earth's magnetic field. The program output is a plot of the magnetic anomaly amplitude versus distance along a path similar to that recorded by a total field magnetometer passing over the array. The array size, object mass, direction of the earth's field and the altitude and direction of the path of the magnetometer are controlled by the user. One hundred and one computer words of storage are required for each pass.

This study was done as part of a Range Clearance Technology task leading to the design of equipment for the detection of unexploded ordnance found on military ranges.

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INTRODUCTION

Previous work involving magnetic anomalies due to a dipole has been restricted to the signal obtained from a single object (1). The purpose of this study was to derive a general expression for the effect of a ferrous object on the earth's magnetic field and adapt it for computer use to allow the calculation of the anomaly due to a three-dimensional array of these objects. This work would not only allow the simulation of the unexploded ordnance scattered about a drop-zone, but would permit the modeling of shrapnel lying near the surface, or the modeling of an area of iron-rich soil of high susceptibility.

Figure 1 shows a plot of anomaly magnitude due to a single ferrous object as seen by a total field magnetometer scanning over the object. Where an array of these objects occurs, it is difficult to visualize the total effect that they will have on the earth's field.

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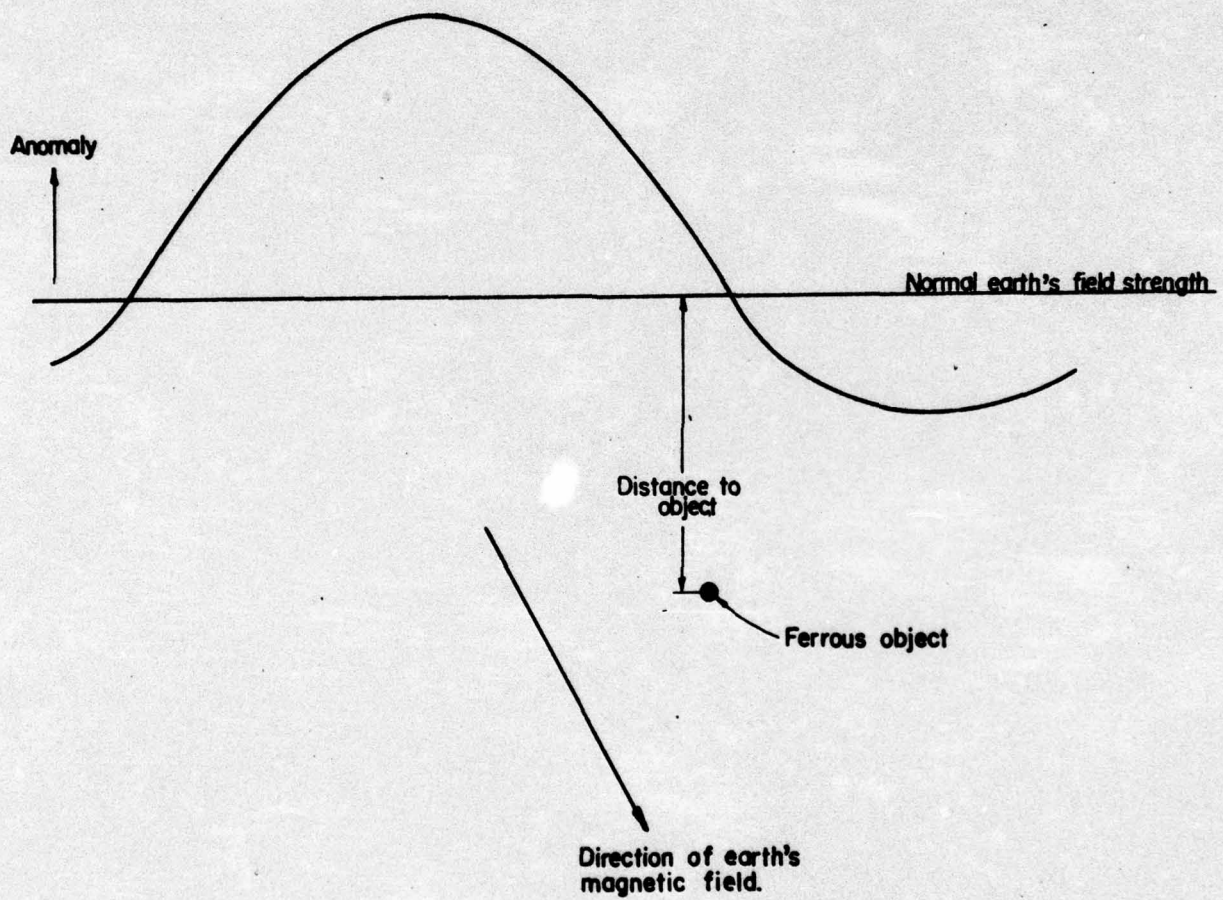


Figure 1 Typical Anomaly Due to a Ferrous Object

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In order to create a smooth plot of the total effect due to an array of objects it is necessary to determine the effect at a large number of points on the path. In this simulation, 101 points were used on a 10" x 10" plot. Where the array contains 100 objects the result is 10,100 calculations per pass. For this reason the problem lends itself well to a computer solution.

THEORY

An object in the earth's magnetic field may cause a distortion of the field depending on the permanent and induced magnetization of the object. It is this distortion, or anomaly, which indicates the presence of an object.

Permanent magnetization is determined by the history as well as composition of the object and can add to or cancel the effect of the induced component. For this study only induced magnetization is considered.

Induced magnetization is a function of the intensity of the ambient field and the magnetic susceptibility of the material in the object:

$$I = KH$$

Where I = induced magnetization per unit volume

K = magnetic susceptibility

H = earth's magnetic field

The magnetic moment of the object is

$$M = IV$$

Where V = volume

Therefore $M = KHV$

The magnetic moment for typical, spherical, man-made iron objects is 10^5 to 10^6 cgs units per metric ton (1).

The anomaly created by an object at a point is a function of the distance to the object and is of the form

$$T = \frac{CM}{r^n}$$

Where C = constant

n = constant

r = distance

Objects which have high length to diameter ratios tend to behave as monopoles, especially if magnetized along their length. That is, their field lines radiate straight out from their ends and the resulting anomaly is inversely proportional to r^2 , or $n = 2$. In reality, they are dipoles which have their poles far apart (1).

In this study, objects of interest have low l/d ratios and behave as dipoles. In this case n is equal to 3, and the anomaly is inversely proportional to r^3 .

A magnetic anomaly due to a dipole is sometimes expressed as two components. One component is due to the field off the end of a dipole. In this case constant C is equal to 2. The other component is from the side of the dipole where C is 1, as shown in reference 2. The first component is projected onto the line joining the object of detection and the point of interest and becomes the radial component T_r . The other is projected onto the perpendicular to it and becomes the tangential component T_ϕ as shown in Figure 2.

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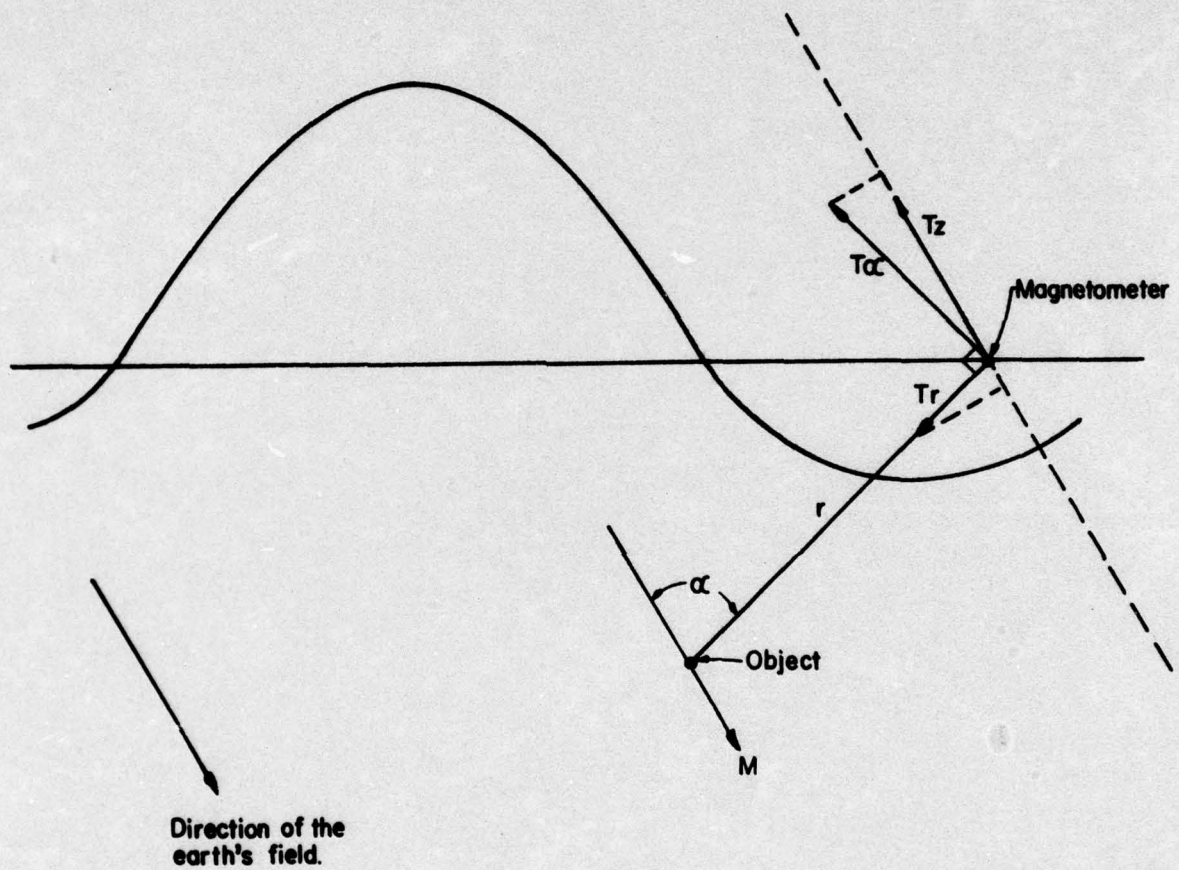


Figure 2 Anomaly Components

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The two components are (1)

$$T_r = \frac{2M \cos \alpha}{r^3}$$

$$T_\alpha = \frac{-M \sin \alpha}{r^3}$$

A three-dimensional co-ordinate system is used to determine the angle α , which is the angle between the earth's field vector and the line between object and magnetometer. The vector describing this line is projected onto a unit vector representing the earth's field. The angle α can then be determined from this projection. The earth's field vector V_1 is defined here (Figure 3).

$$A_1 = \cos A \cos B$$

$$B_1 = \sin A \cos B$$

$$C_1 = \sin B$$

where $V_1 = 1$

The vector V_2 describing the direction and distance from the magnetometer to any object in the array is defined below (Figure 4).

$$A_2 = IX_2 - y \sin \theta + x \cos \theta$$

$$B_2 = IY_2 + y \cos \theta + x \sin \theta$$

$$C_2 = H$$

where H is the height of the magnetometer above the top 2-dimensional array of objects.

$$\text{and } V_2 = \sqrt{A_2^2 + B_2^2 + C_2^2}$$

Vectors $\overline{V_1}$ and $\overline{V_2}$ can be described as

$$\overline{V_1} = A_1 i + B_1 j + C_1 k$$

$$\overline{V_2} = A_2 i + B_2 j + C_2 k$$

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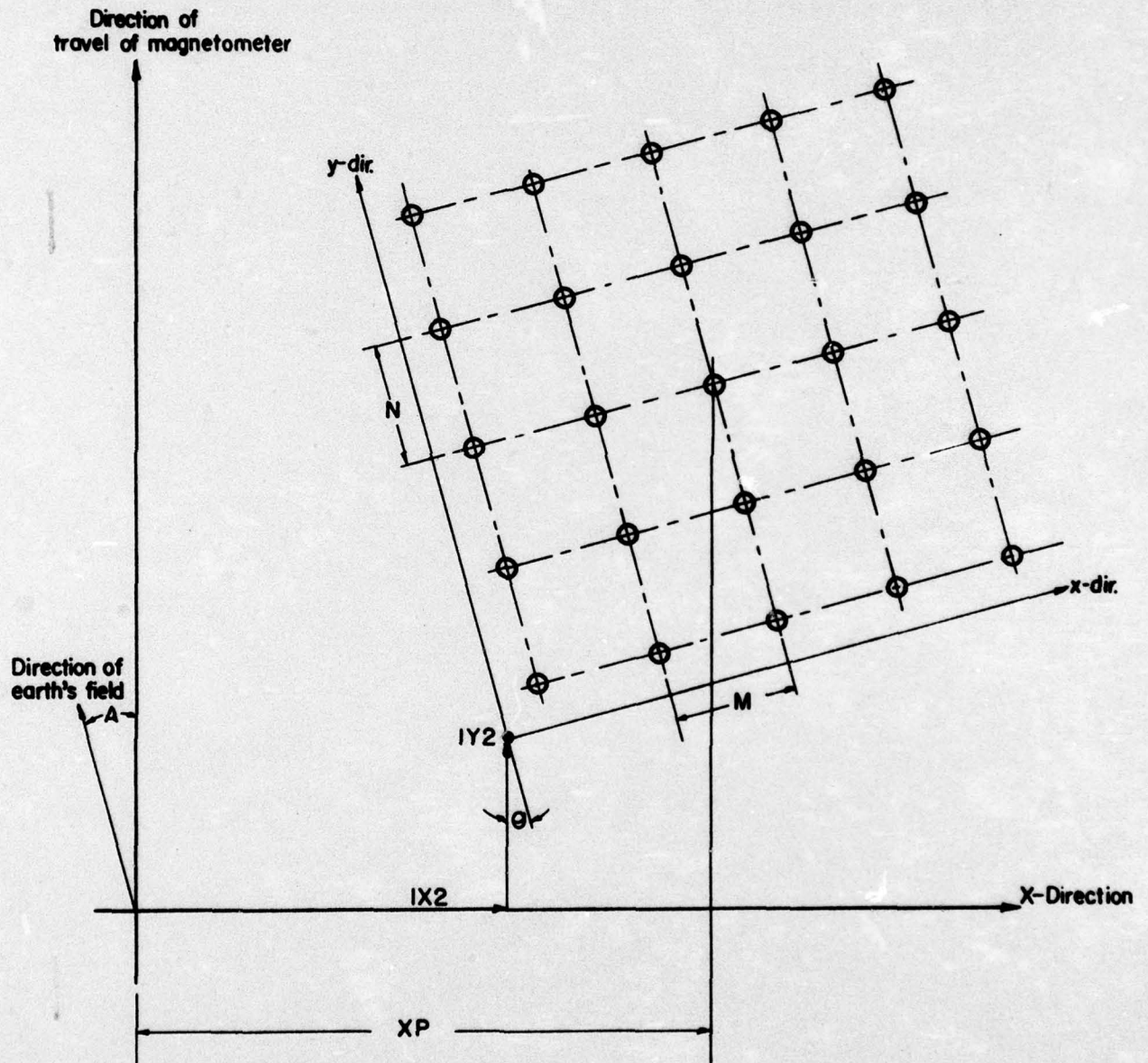


Figure 4 Plan View of Array

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The dot product is used to project one vector on another:

$$\overline{V1} \cdot \overline{V2} = V1V2 \cos \alpha$$

or

$$\cos \alpha = \frac{\overline{V1} \cdot \overline{V2}}{V1V2}$$

but

$$\overline{V1} \cdot \overline{V2} = A1A2 + B1B2 + C1C2$$

and

$$V1V2 = \sqrt{A2^2 + B2^2 + C2^2}$$

Therefore

$$\cos \alpha = \frac{A1A2 + B1B2 + C1C2}{\sqrt{A2^2 + B2^2 + C2^2}}$$

and

$$\sin \alpha = \sqrt{1 - \cos^2 \alpha}$$

We can now find T_r and T_α since

$$T_r = \frac{2M \cos \alpha}{r^3}$$

and

$$T_\alpha = \frac{-M \sin \alpha}{r^3}$$

These components are then projected into the earth's field vector. This is done because a total field magnetometer measures the component of an anomaly very nearly in the direction of the earth's field (1). The direction of the earth's field is easily determined and remains quite constant for a given area.

$$T_z = T_r \cos \alpha + T_\alpha \sin \alpha$$

T_z is the anomaly detected by the magnetometer for one object.

The computer program adds the anomalies for each object in the array and produces plots like those shown in figures 5 - 7. Figure 5 is a west-to-east scan over an array of objects 5 x 5 x 1. Each object appears in a scan this close to the array whereas a scan such as that shown in Figure 6 is far enough above the array of 2 x 2 x 3 to hide the detail of each object. Figure 6 is also an example of a south-to-north scan in a location where the inclination of the earth's field is 45°. All positive inclinations are below the horizontal in this program. Figure 7 shows a scan where the inclination is 73°, approximately the angle in south-eastern Alberta. The symmetry which occurs in a vertical field is noticeably absent at this angle. A magnetic moment of 5×10^5 cgs units/metric ton has been used to produce these curves.

PROGRAM OPERATION

A. Inputs and Operation

The program inputs and its basic operation are explained here.

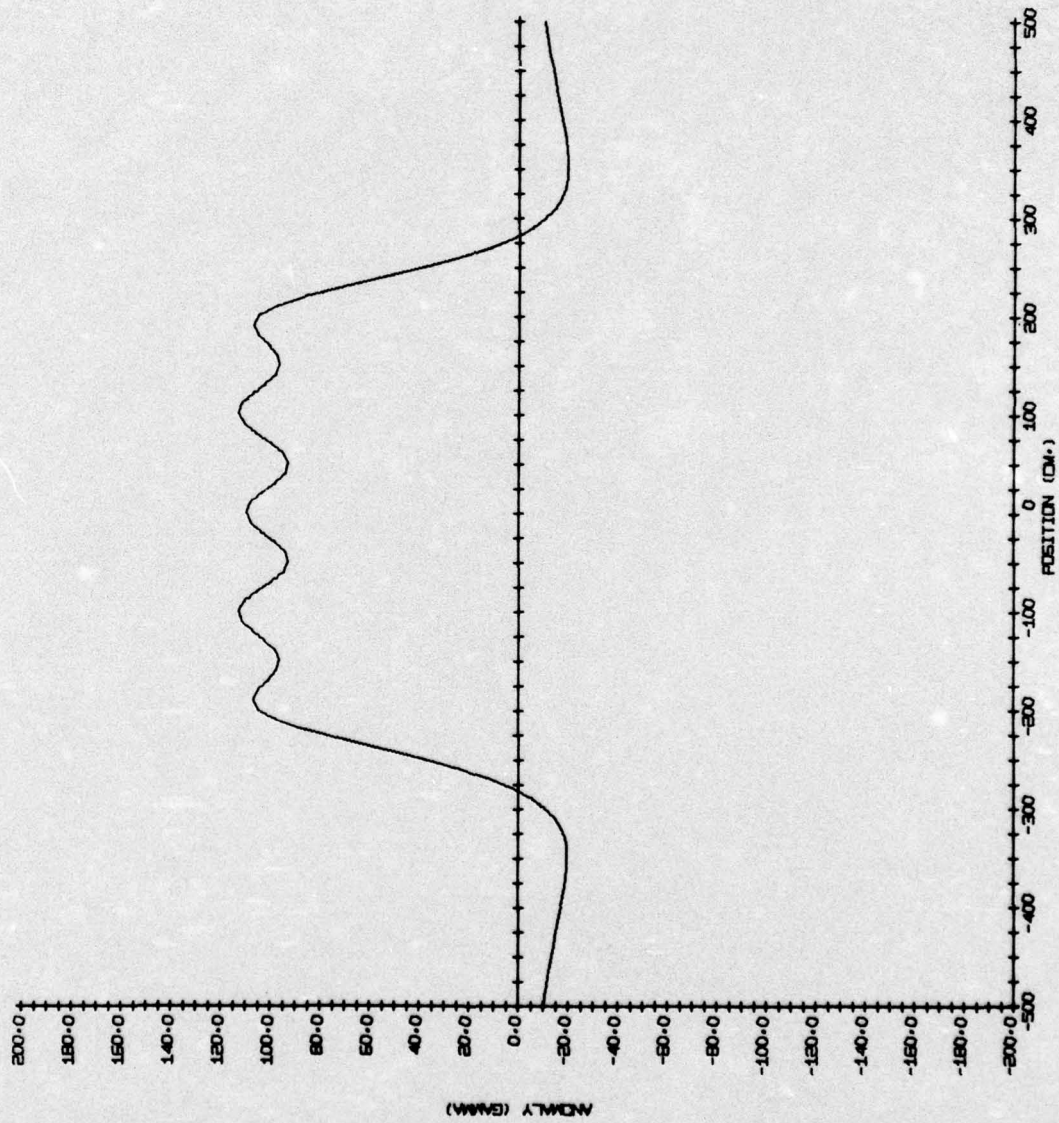
Refer to the main program listing in the Appendix for input formats.

PROBS	number of independent plots done in a run.
THETA	angle of rotation of the array in degrees about a vertical line through the reference point (Figure 4).
A	declination of the earth's field in degrees when the magnetometer heading is north (Figure 3).
B	inclination or dip of the earth's field in degrees.

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HEIGHT,H = 100.00 CM.
 DECLINATION,A = 90.0 DEG
 INCLINATION,B = 90.0 DEG
 DISTANCE,XP = 0 CM.
 X-DIR. SPACING,M = 100. CM.
 Y-DIR. SPACING,N = 100. CM.
 VERTICAL SPACING,P = 10.00 CM.
 ARRAY WIDTH,NOL = 5
 ARRAY LENGTH,NOL = 5
 ARRAY DEPTH,NOL = 1
 ROTATION,THETA = 0. DEG.
 WEIGHT,WT = 1.00 KG.



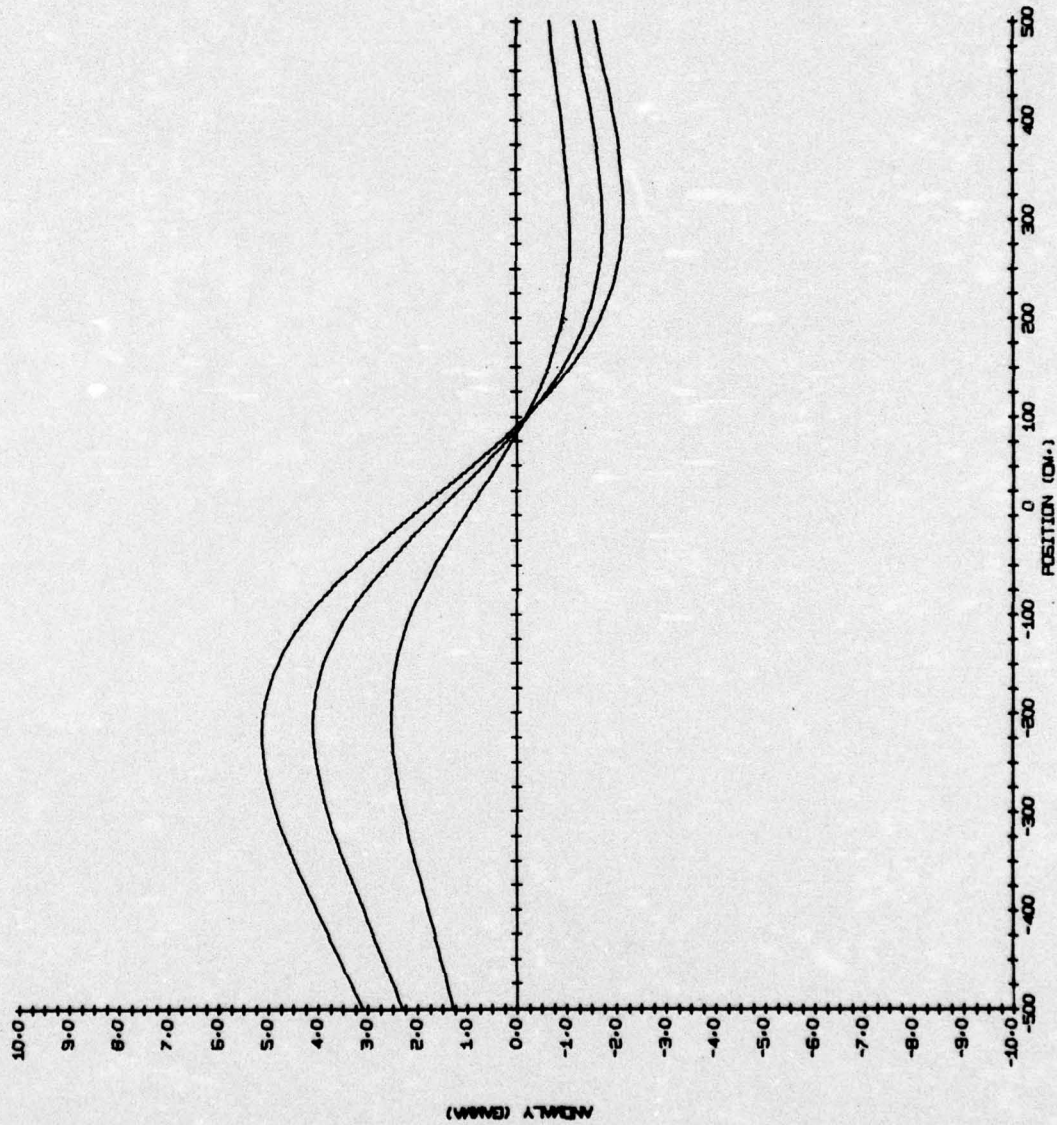
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Figure 5 Anomaly From An Array of Five Objects

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HEIGHT, H = 450.00 CM
 DECLINATION, A = 0.0 DEG
 INCLINATION, B = 45.0 DEG
 DISTANCE, RP = 0 CM
 X-DIR. SPACING, M = 100. CM
 Y-DIR. SPACING, N = 100. CM
 VERTICAL SPACING, P = 80.00 CM
 ARRAY WIDTH, Q, L = 2
 ARRAY LENGTH, R, D = 2
 ARRAY DEPTH, NUM = 3
 ROTATION, THETA = 45. DEG
 WEIGHT, WT = 1.00 KG

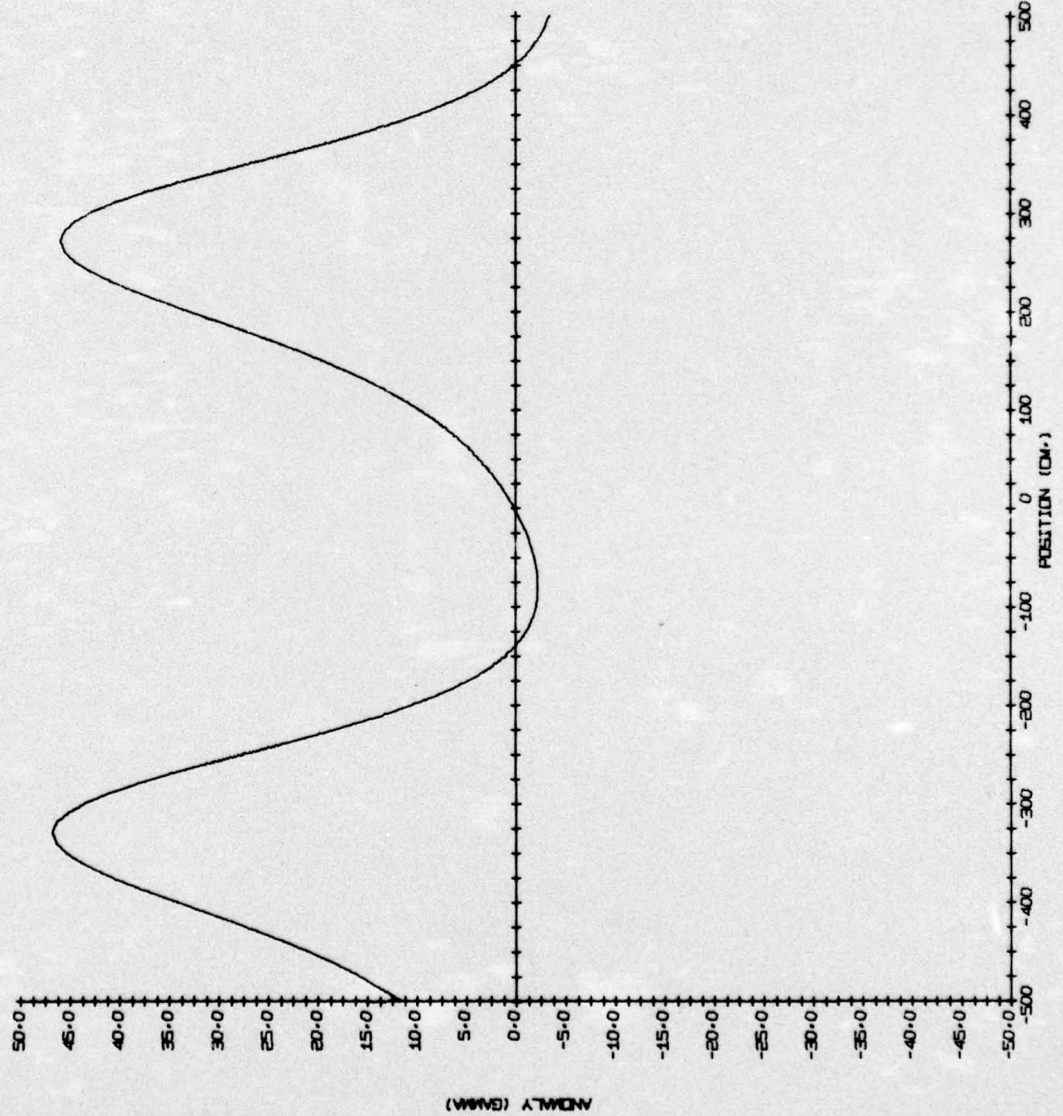


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Figure 6 Anomaly at a Field Inclination of 45°

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HEIGHT,H = 200.00 CM.
 DECLINATION,A = 0.0 DEG.
 INCLINATION,B = 73.0 DEG.
 DISTANCE,XP = 0 CM.
 X-DIR. SPACING,M = 600. CM.
 Y-DIR. SPACING,N = 600. CM.
 VERTICAL SPACING,P = 10.00 CM.
 ARRAY WIDTH,N01 = 1
 ARRAY LENGTH,N02 = 2
 ARRAY DEPTH,NUM = 1
 ROTATION,THETA = 0. DEG.
 WEIGHT,WT = 4.00 KG.

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Figure 7 Typical Anomaly from Two Objects in South-East Alberta

XP	horizontal distance in centimeters from the center of the array to the nearest point of approach on the magnetometer path.
S	horizontal distance in centimeters from the center of the array to the start of the magnetometer path.
F	horizontal distance in centimeters from the center of the array to the end of the magnetometer path.
N01	number of objects in the array in the X-direction (Figure 4).
N02	number of objects in the array in the Y-direction (Figure 4).
H	vertical distance in centimeters from the top two-dimensional array to the nearest point on the magnetometer path.
M	distance in centimeters between objects in the array in the X-direction.
N	distance in centimeters between objects in the array in the Y-direction.
WT	weight of the objects in the array in kilograms.
NUM	maximum number of objects in the array in the vertical direction.
P	vertical distance in centimeters between each two-dimensional horizontal array.

The main program reads in the data cards in the order given above. Then the reference points (XXR, YYR) are defined relative to the center of the array.

Subroutine SCAN is called to do the anomaly calculations. These calculations are all made relative to the reference point. The distance IX2 from the reference point to the closest point on the magnetometer path is printed out prior to SCAN. The subroutine sets the location of the simulated magnetometer according to the user instructions. Then at 101 equally spaced points along this path it determines the anomaly.

The anomaly at a point is determined by finding the angle α and the distance to each object and using the expression derived earlier to obtain the total anomaly from the array. This data is stored in computer core in a two-dimensional array called AA which is dimensioned to AA (101,4). It has room for four magnetometer passes on one graph. Three are shown in Figure 6. The first line plotted is for the top two-dimensional array. A new line is then plotted as an additional two-dimensional array is added below the last and the effect of all present arrays is calculated. In Figure 6 three lines are shown indicating a three-dimensional array, three layers vertically, the last line being calculated for the entire array. Array size is set by the user. As the data is being stored, the maximum anomaly among the 303 points is determined for use later. When storage is complete, control is returned to the main program.

Subroutine SKALE is called and uses the maximum anomaly point found in SCAN to set an appropriate scale for the y-axis of the plotter output.

Again control is returned to the main program. The line printer will output the maximum anomaly point T and the maximum scale height XMAX which were found in SCAN and SKALE.

The grid is set with four tick marks per inch for ten inches on both the X and Y axis of the plotter.

Subroutine ROWND is called to round off the X axis scale if necessary. The main program then instructs the plotter to print the X axis numbers, one per inch as required by the scale, and the X axis title is printed. The same procedure occurs for the Y axis.

The rest of the main program plots the data stored in array AA.

When the plot is finished the plotter pen moves to a new location ready to begin another graph if instruction PROB requires it.

B. Output

The main program output is a graph of the magnetic anomaly due to an array of ferrous objects. At the side of the graph is a listing of the input parameters to the program. The anomaly scale in gammas is printed along the vertical axis. The distances in centimeters printed on the horizontal axis give the horizontal component of the distance from the geometric center of the object array to the simulated location of the magnetometer. The program input lists the desired start and finish distance from the magnetometer to the array center. These values are transformed into the horizontal scale of the graph.

As mentioned in SECTION A, the magnetometer heading is always assumed to be north. However, by adding to the declination angle, the effective heading can be changed. Also, the entire array may be rotated about its reference point (SECTION A) to compensate for this new heading (Figure 4).

The distance XP indicates the closest distance that the magnetometer comes to the array center. When XP is zero, the detector is passing directly over the geometric center of the array.

Appendix A

Program Listing

```

// FOR
*ONE WORD INTEGERS
*LIST SOURCE PROGRAM
*LIST SURROUTINE SCAN(M,N,H,N01,N02,WT,AA,THETA,A,B,IX2,L,NUM,Z,P,T,S,F)
INTEGER S,F
REAL M,N,MW
DIMENSION AA(101,4)
T = 0.
MM = 5.E 10
A1 = COS(A) * COS(R)
A1 = SIN(A) * COS(R)
C1 = SIN(R)
V1 = 1.
DO 200 K=1,NUM
  IV2=L
  LL=1
  ANOM = 0.0
  DO 100 I=1,N01
    IF (I-1)/2,2,3
      2 X = X + W/2.
      3 X = X + M
      4 Y = C*0
      DO 100 J=1,N02
        IF (J-1)/5,5,6
          5 Y = Y + N/2
          6 Y = Y + N
          7 A2 = IX2 - Y * SIN(THETA) + X * COS (THETA)
          8 Z = IV2 + Y * COS (THETA) + X * SIN (THETA)
          C2 = M
          V2 = SORT(A2**2 + B2**2 + C2**2)
          COSTH = (A1*A2+B1*B2+C1*C2)/SORT((A1**2+B1**2+C1**2)*(A2**2+B2**2+C2**2))
          1 SINTH = SORT(1.-COSTH**2)
          TR = 2*MM*COSTH/V2**3*WT
          TTH = -MM*SINTH/V2**3*WT
          T2 = TR*COSTH + TTH * SINTH
          ANOM = ANOM + T2
          100 CONTINUE
          AA (LL,K) = ANOM
          D = 0.
          DO 9 11 = 1,K
            9 D = D + AA(LL,11)
            IF (ABS(T)-ABS(D))11,13,13
          11 T = ABS(D)
          13 IV2 = IV2 - ( S+F)/100
          LL=LL-1
          IF LL-101 110,10,15
          15 #25(PK)
          200 CONTINUE
          RETURN
          END
FEATURES SUPPORTED
ONE WORD INTEGERS
CORE REQUIREMENTS FOR SCAN
COMMON 0 VARIABLES 64 PROGRAM 526
RELATIVE ENTRY POINT ADDRESS IS 004D (HEX)
END OF COMPILATION
// DUP

// FOR
*ONE WORD INTEGERS
*LIST SOURCE PROGRAM
*LIST SURROUTINE SCALE(T,TMAX)
DIMENSION TEST(29)
DATA TEST/10000.,50000.,25000.,20000.,10000.,5000.,2500.,2000.,1000.,500.,250.,200.,100.,50.,25.,20.,10.,5.,2.,5.,2.,0.,1.,0.,0.,5.,0.,25.,20.,20.,0.,1.,0.,05.,0.,025.,0.,025.,0.,01/
IF (T-100000.)20,30,30
IF (T-101)30,30,40
30 TMAX=T
RETURN
40 DO 50 I=2,29
  IF (T-TEST(I))50,50,60
50 CONTINUE
60 TMAX=TEST(I-1)
RETURN
END
FEATURES SUPPORTED
ONE WORD INTEGERS
CORE REQUIREMENTS FOR SCALE
COMMON 0 VARIABLES 60 PROGRAM 74
RELATIVE ENTRY POINT ADDRESS IS 0042 (HEX)
END OF COMPILATION
// DUP

// FOR
*ONE WORD INTEGERS
*LIST SOURCE PROGRAM
*LIST SURROUTINE ROUND (WORD,NUM)
DIMENSION TENS(6)
DATA TENS/1,0,10,0,100,0,1000,0,10000,0,100000,0,0/
DO 1 I = 1,6
  IF (TENS(I)-ABS(WORD))11,99,2
  1 CONTINUE
  IF (NUM)99,99,10
  3 IF (NUM-6)15,15,99
  10 TEMP = WORD/TENS(NUM)
  15 IF (TEMP-32767)4,4,99
  4 TEMP=TEMP/TENS(NUM)
  TEST = TEMP-FLOAT(TEMP)
  TEMP = FLOAT (TEMP)
  IF (TEST)20,99,30
  20 IF (TEST+0.5)22,22,25
  22 TEMP = TEMP-1.0
  25 WORD = TEMP/TENS(NUM)
  RETURN
  30 IF (TEST-0.5)40,35,35
  35 TEMP = TEMP + 1.0
  40 WORD = TEMP/TENS(NUM)
  99 RETURN
  END
FEATURES SUPPORTED
ONE WORD INTEGERS
CORE REQUIREMENTS FOR ROUND
COMMON 0 VARIABLES 22 PROGRAM 176
RELATIVE ENTRY POINT ADDRESS IS 001E (HEX)
END OF COMPILATION
// DUP

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// FOR
*IOCS(CARD)
*IOCS(1132 PRINTER)
*ONE WORD INTEGERS
*IOCS(PLOTTER)
*LIST SOURCE PROGRAM
INTEGER PRORS, XP, S, F
REAL M, N
DIMENSION AA(101,4)
READ (2, 2) PRORS
2 FORMAT(13)
DO 7 JLL=1, PRORS
  READ (2, 4) THETA
4 FORMAT(F9,1)
  THETA = THETA * 2. * 3.14/360.
  READ(2, 6) A, B
6 FORMAT(F9,1,F9,1)
  A = A + 90.
  A = A * 2. * 3.14/360.
  B = B * 2. * 3.14/360.
  READ(2, 8) XP
8 FORMAT(110)
  READ(2, 10) S, F
10 FORMAT(110,110)
  READ (2,12) NO1, NO2
12 FORMAT (15,15)
  READ (2,14) H
14 FORMAT (F10,2)
  Z = H
  READ (2,16) M, N
16 FORMAT (F10,2,F10,2)
  READ (2,18) WT
18 FORMAT (F10,2)
  CONVERT TO METRIC TONS
  WT = WT/1000.0
  READ (2,20) NUM
20 FORMAT (13)
  READ (2,22) P
22 FORMAT (F10,2)
  XXR = M*(NO1-1)/2. + W/2.
  YYR = N*(NO2-1)/2. + W/2.
  TL = SORT (XXR**2 + YYR**2)
  AN = ATAN (YYR/XXR)
  ANTH = AN + THETA
  XU = COS (ANTH) * -L
  CALL ROWND (XU,1)
```

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```
IX2 = XP - IFIX(XU)
WRITE (3,1)
1 FORMAT ('1')
WRITE(3, 24) IX2
24 FORMAT ('1',IX2,'110)
RAY = SIN(ANTH)*TL
CALL ROWND (RAY,1)
L = S - IFIX(RAY)
IY = S + F + L
CALL SCAN (M,N,H,NO1,NO2,WT,AA,THETA,A,B,IX2,L,NUM,Z,P,T,S,F)
CALL SCALE (T,XMAX)
WRITE (3,26) T,XMAX
26 FORMAT ('0',T,'1',F15,6,3X,'XMAX ='1,E15,6)
Y=1./XMAX*10./2.
X=10./FLOAT(S+F)
PF=FLOAT(L)
PU=XMAX
CALL SCALF(X,Y,PF,PU)
XXY=.025*FLOAT(S+F)
CALL FGRID(0,PE,PU,XXY,40)
CALL FGRID (0,PE,0.0,XXY,40)
YY = XMAX/40.
CALL FGRID(1,PE,PU,YY,80)
PO=-.35*FLOAT(S+F)/10.-F.OAT(L)
KO = -S
DO 9 II = 1,11
  YYY=-.04*XMAX-XMAX
  CALL FCHAR (PO, YYY, .01,0.1,0.0)
  WRITE (7,28) KO
28 FORMAT(15)
  PO=PO+FLOAT(S+F)/10.
  KO=KO+(S+F)/10
9 CONTINUE
  XY=.44*FLOAT(S+F)-FLOAT(L)
  XX=-.08*XMAX-XMAX
  CALL FCHAR ( XY, XX,0.1,0.1,0.0)
  WRITE (7,30)
30 FORMAT('POSITION (CM,1)')
  PO=-.005*XMAX-XMAX
  OK = -XMAX
  DO 11 JJ = 1,21
    XYX=-FLOAT(S+F)*.07-FLOAT(L)
    CALL FCHAR (XYX,PO,.1,0.1,0.0)
    CALL ROWND (OK,2)
    WRITE (7,32) OK
32 FORMAT(F6,1)
```

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```
PO = PO + .1 * XMAX
OK=-XMAX+FLOAT(JJ)/10.0*XMAX
11 CONTINUE
  YX = -FLOAT(S+F)/10.-FLOAT(L)
  XXX=.85 *XMAX-XMAX
  CALL FCHAR ( YX, XXX,C.1,0.1,1.57)
  WRITE (7,34)
34 FORMAT ('ANOMALY (GAMMA)')
  H = Z
  WRITE (3, 3)
  3 FORMAT ('0')
  DO 13 K=1,NUM
    LL=1
    HH=-FLOAT(L)
25 A1=0.
    DO 15 I1=1,K
      A1=A1+AA(LL,I1)
15 IF(A1-XMAX) 17,19,21
17 IF(A1+XMAX) 23,19,19
23 A1=-XMAX
    GO TO 19
21 A1= XMAX
    GO TO 19
19 CALL FPLT(-2,HH,A1)
    LL=LL+1
    HH=HH+FLOAT((S+F)/100)
    IF(HH-(IY-2*L)) 25,25,27
27 CALL FPLT (+1,HH,A1)
13 CONTINUE
  A = A/2./3.14*360.
  B = B/2./3.14*360.
  CALL FCHAR ((-L + 11./X), 0.54 * XMAX, 0.1,0.1,0.0)
  WRITE(7, 36) H
36 FORMAT ('HEIGHT,M'11X='1,F9,2,1X'CM,1)
  CALL FCHAR ((-L + 11./X), 0.48 * XMAX, 0.1,0.1,0.0)
  A = A - 90.
  WRITE (7,38) A
38 FORMAT ('DECLINATION,A'6X='1,F9,1,2X'DEG,1)
  CALL FCHAR ((-L + 11./X), 0.42 * XMAX, 0.1,0.1,0.0)
  WRITE(7, 40) B
40 FORMAT ('INCLINATION,B'6X='1,F9,1,2X'DEG,1)
  CALL FCHAR ((-L + 11./X), 0.36 * XMAX, 0.1,0.1,0.0)
  WRITE (7,42) XP
42 FORMAT ('DISTANCE,XP'8X='1,I6,4X'CM,1)
  CALL FCHAR ((-L + 11./X), 0.30 * XMAX, 0.1,0.1,0.0)
  THETA = THETA / 2./ 3.14*360.
```

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WRITE(7, 44) M
44 FORMAT ('X-DIR, SPACING,M'3X='1,F7,0,3X'CM,1)
  CALL FCHAR ((-L + 11./X), 0.24 * XMAX, 0.1,0.1,0.0)
  WRITE(7,46) N
46 FORMAT ('Y-DIR, SPACING,N'3X='1,F7,0,3X'CM,1)
  CALL FCHAR ((-L + 11./X), 0.18 * XMAX, 0.1,0.1,0.0)
  WRITE (7,58) P
58 FORMAT ('VERTICAL SPACING,P'1X='1,F9,2,1X'CM,1)
  CALL FCHAR ((-L + 11./X), 0.12 * XMAX, 0.1,0.1,0.0)
  WRITE (7,48) NO1
48 FORMAT ('ARRAY WIDTH,NO1'4X='1,I6)
  CALL FCHAR ((-L + 11./X), 0.06 * XMAX, 0.1,0.1,0.0)
  WRITE (7,50) NO2
50 FORMAT ('ARRAY LENGTH,NO2'3X='1,I6)
  CALL FCHAR ((-L + 11./X), 0.00 * XMAX, 0.1,0.1,0.0)
  WRITE (7,56) NUM
56 FORMAT ('APRAY DEPTH,NUM'4X='1,I6)
  CALL FCHAR ((-L + 11./X),0.06 * XMAX, 0.1,0.1,0.0)
  WRITE (7,52) THETA
52 FORMAT ('ROTATION,THETA'5X='1,F7,0,3X'DEG,1)
  CALL FCHAR ((-L + 11./X),0.12 * XMAX, 0.1,0.1,0.0)
  CONVERT TO KG.
  WT = WT * 1000.0
  CALL ROWND (WT,3)
  WRITE (7,54) WT
54 FORMAT ('WEIGHT,WT'10X='1,F9,2,1X'KG,1)
  APP = 1.7*(FLOAT(S+F))-FLOAT(L)
  CALL FPLT (+3,APP,-XMAX)
7 CONTINUE
  CALL EXIT
  END
```

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